GEOPHYSICAL RESEARCH LETTERS, VOL. 8, NO. 5, PAGES 449-452, MAY 1981

PRELIMINARY SPECTRAL ANALYSIS OF NEAR-REAL-TIME RADON DATA

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Abstract. Fast Fourier analysis of the near-real-time radon data collected since 1977 by the Caltech automated radon-thoron monitoring system has been carried out in order to determine if any characteristic frequency components are present that can be associated either with precursors to seismicity or with environmental factors. Preliminary results indicate that during "quiet" periods with low seismicity and no rainfall the spectral power is distributed as 1/f. Before four local earthquakes a departure from this 1/f behavior was observed at low frequency. During periods of heavy rainfall an increase in both low and high frequency power was observed. The spectral power of the large radon anomaly observed prior to the October 15, 1979 Imperial Valley earthquake was found to have a 1/f distribution but with power at all frequencies about four times greater than that of data from "quiet" periods.

Introduction

The California Institute of Technology operates a system of automated radon-thoron monitors for earthquake prediction research in southern California. At present this network includes eight stations in the Transverse Ranges. Melvin et al. [1978, 1980] have described the design and operation of the monitors, and Shapiro et al. [1980a, 1980b, 1981] have reported on data obtained from the network. During the period from the inception of monitoring at the Kresge site in 1977, anomalies have been observed before some local earthquakes [Shapiro et al., 1980a,b]; and a major radon anomaly was observed starting in 1979 that apparently was related to a strain event that also may have been related to the 6.6 M Imperial Valley earthquake [Shapiro et al., 1981]. Significant changes in radon levels at some sites also have been observed following intense rainfall [Shapiro et al., 1980c].

A modified Apple II microcomputer has been used to carry out fast Fourier analysis of data collected by the radon-thoron monitoring network. Except for background subtraction from each of the three daily radon counts, there was no treatment of the data prior to analysis. We have examined the resulting power spectra for possible correlations with seismic activity, environmental factors such as temperature and rainfall, and earth tides.

Results and Discussion

Numerous spectra from "quiet" periods with no significant local seismicity or heavy rainfall were Fourier analyzed, and the spectral power generally was found to be distributed approximately as 1/f. Such a spectral distribution can be shown to be characteristic of systems in which a white noise source is filtered by being coupled to a reservoir through diffusion. A common example would be a random heat source coupled to a thermal reservoir. Similarly, the Fourier transform of a radioactive source (such as the radium in the rock matrix which supports the radon concentration) is a white noise spectrum. This in turn is coupled to the groundwater in the pore spaces of rock. It is quite reasonable to expect that in situations where the emanating power, the porosity of the rock, and the flow velocity of pore fluids are not changing; the spectral power of the radon concentration in the ground water would exhibit a 1/f distribution. Any variance from a 1/f distribution would imply that the source spectrum is not a white noise spectrum, or that the emanating power, rock porosity, or fluid flow velocity are not all time independent.

Figure 1 shows a typical spectrum from the Kresge monitoring site during a quiet period in 1977. The quantity plotted is not the spectral

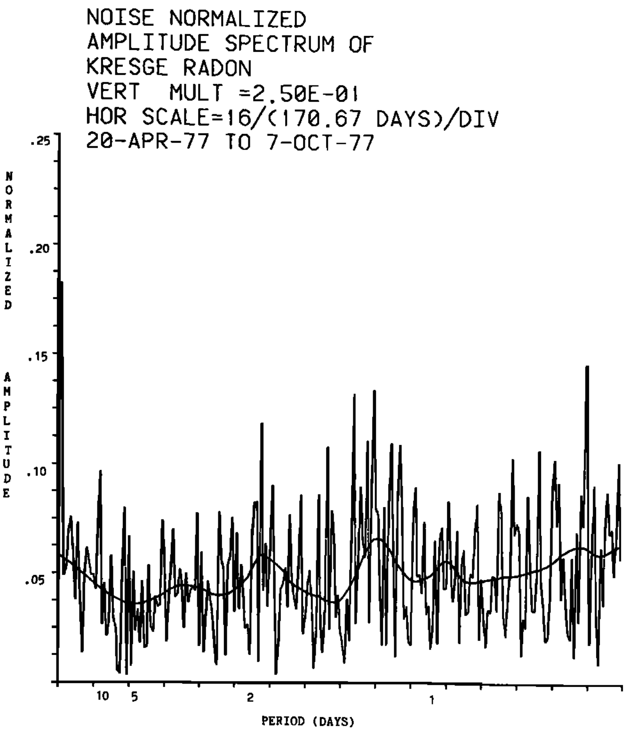

Fig. 1. Noise normalized amplitude spectrum derived from Kresge radon data from the period 20 April 1977 to 7 October 1977. This was a period with little rainfall and no significant seismicity in the vicinity of the station. The smooth line is a 10 point running average of the data.

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Paper number 1L0700.
0094-8276/81/001L-0700$01.00

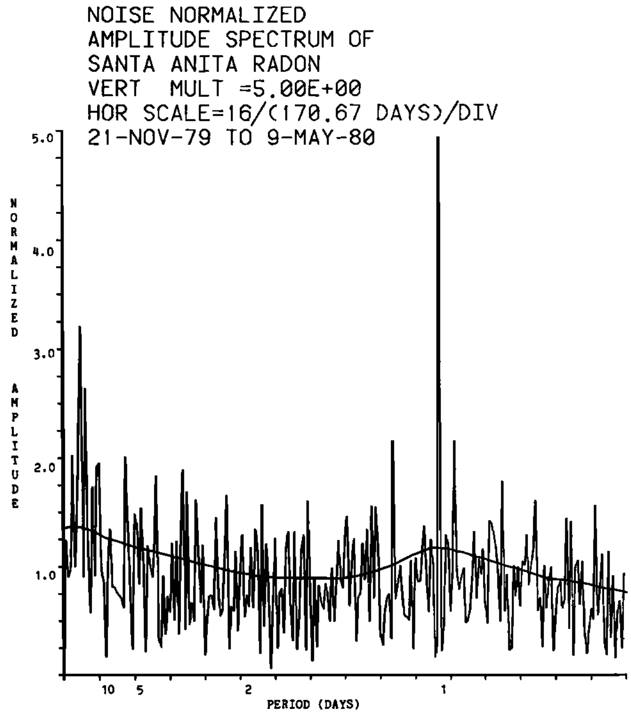

Fig. 2. Noise normalized amplitude spectrum derived from Santa Anita radon data from the period 21 November 1979 to 9 May 1980. The large spike corresponds to a frequency of 1 cycle/day. The smooth line is a 10 point running average of the data.

power but (power xfrequency)$^{1/2}$, so that the envelope of this plot would be flat for a perfect 1/f spectrum. Spectra normalized in this manner will be referred to as noise normalized spectra (NN-spectra). The NN-spectrum in Figure 1 has a nearly flat envelope, particularly for the low frequencies, which indicates that the source spectrum is indeed distributed as 1/f. This also can be seen by examining the ten run running average of the data (smooth line) for periods between 2 and 30 days.

In Figure 2, a NN-spectrum of data from another Caltech radon monitoring site (Santa Anita canyon) is plotted. In this spectrum a large spike is seen at a frequency of 1 cycle/day. Power at this frequency is seen at a few of the monitoring sites on the Caltech network, and possibly may reflect daily thermal effects at these locations. At some sites on the network (Kresge, Dalton Canyon, Santa Anita Canyon), the amplitude of this diurnal cycle has changed substantially at times. These changes usually have been correlated with changes at other frequencies.

The borehole at Santa Anita is dry, and the envelope and average of the NN-spectra from this monitor do not exhibit the same flatness in the 2 to 30 day periods that spectra from the other water-filled boreholes on the network exhibit.

Once the shape of a spectrum derived from data obtained from a "quiet" period had been established, it became possible to search for features in the spectra that might be correlated with seismicity or with sudden environmental changes. Figure 3 shows the NN-spectrum of data recorded at the Kresge site (at the time this was the nearest monitor) before the 5.0 M Malibu earthquake which occurred on 1 January 1979 about 54 km to the west of the monitor. In this spectrum there is a noticable departure from 1/f behavior at low frequencies, although there is not much change in the overall power in the spectrum. This can be seen by comparing the slope of the running average in the 2 to 30 day range in Figure 3 with that of Figure 1 for the same 2 to 30 day range. This behavior also was seen in data from the nearest monitor before three other local earthquakes (M = 3.2, 13 km south of Kresge on 22 December 1977; M = 3.0, 12 km southwest of Stone Canyon on 27 January 1981; M = 3.2, 20 km southwest of Stone Canyon on 29 January 1981), and may be characteristic of radon precursors to local earthquakes. The appearance of low frequency components in the NN-spectra began 4 to 8 weeks before these earthquakes, which would be enough time to identify their presence prior to the event. (In the case of the two most recent events, the appearance of low frequency components in data from the nearest monitor - Stone Canyon - was recognized about a week before the first event.)

It should be noted that all the earthquakes to date for which the departure from 1/f behavior at low frequency was observed took place in early winter (before the onset of heavy rainfall, however), so it is possible that the departure may partly reflect seasonal environmental

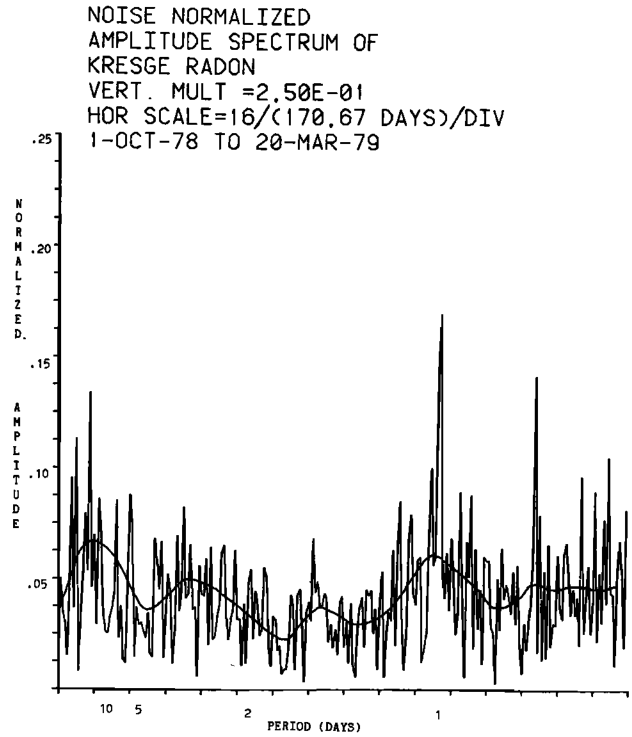

Fig. 3. Noise normalized amplitude spectrum derived from Kresge radon data from the period 1 October 1978 to 20 March 1979. The Malibu earthquake (M = 5.0, 54 km west of Kresge) occurred on 1 January 1979. The smooth line is a 10 point running average of the data. Note the departure from 1/f behavior at low frequencies.

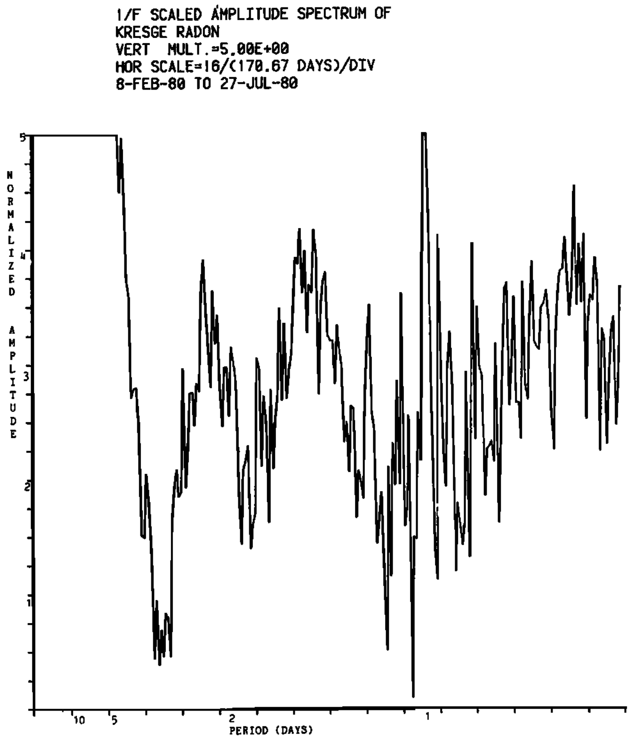

Fig. 4. Noise normalized amplitude spectrum derived from Kresge radon data from the period 8 February 1980 to 27 July 1980. This period included several severe winter rainstorms.

factors. However, in the case of the two recent earthquakes near Stone Canyon the departure from 1/f behavior was seen only in the data from the Stone Canyon monitor. If seasonal factors were primarily responsible for the change in the spectrum, this change should have been seen at other monitors on the network.

Effects of Rainfall

The effects of heavy rainfall can be seen in Figure 4 which is a NN-spectra of data from Kresge during the winter of 1979-80 which was characterized by a series of intense rainstorms [Shapiro et al., 1980b]. In this spectrum the intermediate and high frequencies are enhanced, so this type of response can be distinguished easily from the variations that appear to be associated with nearby earthquakes.

Imperial Valley Earthquake

The NN-spectrum shown in Figure 5 was derived from data collected at the Kresge monitoring site before the Imperial Valley earthquake of 15 October 1979 (M = 6.6). This event occurred about 290 km to the southeast of the monitor, and was preceded by anomalies in geochemical, geophysical, and geodetic signals at scattered locations in the Transverse Ranges of southern California and by a seimicity anomaly in the Imperial Valley [Shapiro et al., 1981 and references therein]. Obvious anomalies were present in the radon time series from our Kresge and Dalton Canyon monitors prior to this event.

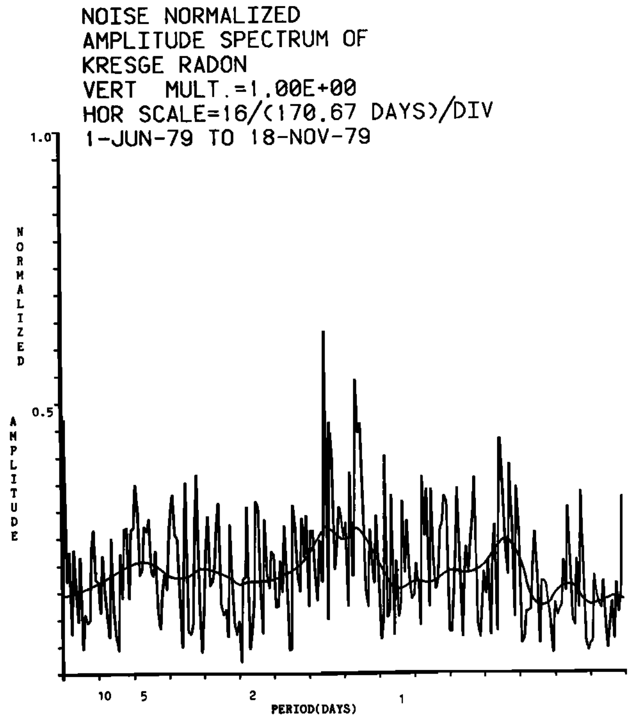

Fig. 5. Noise normalized amplitude spectrum derived from Kresge radon data from the period 1 June 1979 to 18 November 1979. The Imperial Valley earthquake (M = 6.6, 290 km southeast) occurred on 15 October 1979. The scale in this figure has been compressed by a factor of four compared to that of Figure 1. The smooth line is a 10 point running average of the data.

The NN-spectrum looks quite similar to that obtained during a "quiet" period (Figure 1) except that the amplitude of the variations is about 4 times greater. It may be possible, thus, to determine if a "precursor" is local or regional by these differences in frequency content.

Conclusions

The preliminary nature of these results should be emphasized. Only a small number of earthquakes with magnitude >3.0 have occurred in the vicinity of the network, and only one large event has been observed in the vicinity of the network. Much more data must be accumulated before the value of spectral analysis in the recognition of precursory radon signals can be confirmed.

Acknowledgments. The work in this paper was supported in part by U.S. Geological Survey Contracts 14-08-0001-17734 and 14-08-0001-19752 at Caltech.

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(Received February 12, 1981;
accepted April 21, 1981.)